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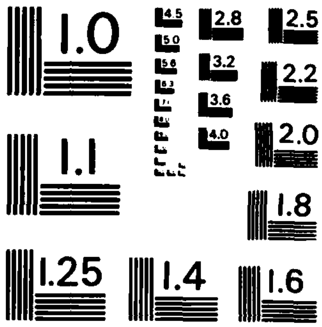

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STOCHASTIC ROTOR BLADE DYNAMICS

Final Report

by

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Helicopter rotor dynamics, random vibration, stochastic stability, stochastic response.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of a theoretical investigation into the effects of atmospheric turbulence on the dynamical behavior of helicopter rotor blades are reported. Turbulence is found to destabilize the uncoupled flapping and coupled flapping-torsional motions; however, it stabilizes the coupled flapping-lagging motion by effectively increasing the damping in the least stable lead-lag mode. When a motion is stable, turbulence contributes to random

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fluctuation from the average system response. Under a trim condition, which suppresses the first harmonics in flapping, the effect of turbulence, as measured by the standard deviation of system response, is of the same order of magnitude as the second harmonics in the deterministic (i.e. an idealized turbulence-free) solution.

Problem Description

In the service life of a helicopter, numerous encounters with clear-air or thunderstorm turbulence can be expected. Furthermore, because of the very nature that lift is generated by blade rotation, some level of self-created turbulence is also unavoidable. Therefore, random turbulence in the atmosphere should be included in a realistic analysis of helicopter dynamics.

The theoretical investigation reported in this document is concerned with the behavior of rotor blades in a turbulent flow. Specifically, answers are sought to two questions: (1) how does turbulence affect the motion stability of a blade system? (2) if the motion is stable, then by what amount does it deviate from that computed from a deterministic analysis in which the turbulence is ignored?

Mathematical Models

A. Structural Models

A-1. Three types of motion are considered: uncoupled flapping, coupled flapping and torsion, coupled flapping and lagging.

A-2. For flapping and lagging, the blades are assumed to be rigid and centrally hinged, with elastic restraints at the hinge. The degree of structural coupling between flapping and lagging is represented by a coupling parameter.

A-3. For torsional motion, the blades are assumed to be elastic and the torsional angle varies spanwise linearly.

A-4. The mass and elastic centers coincide along the one-quarter chord line.

B. Aerodynamic Models

B-1. Flow is incompressible and sectionally two dimensional; i.e. the spanwise flow is neglected.

B-2. Forces acting on a blade are computed from the steady aerodynamic theory for flapping and lagging motions, and from the quasi-steady aerodynamic theory for torsional motion.

B-3. The lift slope is the same constant in the normal and reversed flows.

B-4. Flow separation and stall do not occur.

C. Turbulence Model

C-1. Turbulence field is statistically stationary in time and homogeneous in space; i.e. the statistical properties are unchanged with respect to the change of time and spatial coordinate orgins.

C-2. The speed of a rotor blade (rotation plus forward motion) is much greater than the convection speed of the turbulence; therefore, the turbulence has a short correlation time when observed on a moving blade.

These simplifying assumptions are made to enable a meaningful and useful analysis of a complicated dynamic system to be completed with a reasonable length of time, while capturing the essential features of the physical phenomena involved.

Summary of Important Results:

(1) Turbulence plays two distinct roles in rotor dynamics: (a) as parametric excitations which affect the motion stability, and (b) as external excitations which cause random deviation from the idealized motions predicted by determinic analyses in which turbulence is ignored.

(2) Parametric random excitations appear in the coefficients in the equations of motion. In contrast, external excitations appear in the inhomogeneous terms on the right hand sides of the equations.

(3) Uncoupled flapping and coupled flapping-torsion are essentially linear phenomena for which the turbulence components in the plane of blade rotation (horizontal components) are parametric and the turbulence component normal to the rotational plane (vertical component) is external.

(4) Horizontal turbulence components de-stabilize the uncoupled flapping and coupled flapping-torsional motions. However, since these motions are extremely stable for usual helicopter blade configuration and flight conditions, the turbulence level must be unusually high in order for unstable motion to occur.

(5) Coupled flapping-lagging motion is nonlinear. However, turbulence induced random perturbation from the idealized no-turbulence motion is essentially linear. In the linearized equations for the perturbed motion, the vertical turbulence dominates, and it appears both in the coefficients and as inhomogeneous terms.

(6) The vertical turbulence component stabilizes the coupled flapping-lagging motion by increasing the damping in the least-stable, lead-lag mode. It has the same effect as an increase in the profile drag coefficient.

(7) When a motion is stable, turbulence contributes to the random fluctuation from the average system response. Under a trim condition which suppresses the first harmonics of flapping response, the effect of turbulence, as measured by the standard deviation of the response, is of the same order of magnitude as the second harmonics in the deterministic

(i.e. idealized turbulence free) solution.

(8) The constant coefficient approximation using the method of multiblade coordinates yields essentially the same stability results whether one time-averages both the stochastic and deterministic terms or time-averages only the stochastic terms. The constant coefficient approximation was found to be accurate only for trimmed rotors.

For additional information, the reader is referred to the publications listed in the next section.

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